Jurnal Kejuruteraan 32(2) 2020: 271-280
https://doi.org/10.17576/jkukm-2020-32(2)-11

Initial Assessment of Indoor Environmental Condition and Thermal Comfort of Malaysia Heritage Mosque

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Received 26 May 2019, Received in revised form 29 August 2019
Accepted 9 October 2019, Available online 30 May 2020

ABSTRACT

Heritage mosques are the gems of the country as they preserve the history of local communities and nation. Many studies have been executed on the architectural characteristics of Malaysia heritage mosques. However, the empirical studies on its indoor environmental condition and thermal comfort are still lacking. Therefore, the objective of this study is to identify the indoor environmental condition and thermal comfort of Malaysia heritage mosque by using the field measurement method. The selected heritage mosque for this study is Masjid Tanah, which is located at Masjid Tanah, Alor Gajah, Melaka. Two multiparameter ventilation meters were used in the field measurement. The variables measured were air temperature and air velocity, while the indoor predicted comfort temperature was calculated using the adaptive thermal comfort model equation. The results show that the average indoor air temperatures were lower than the average outdoor air temperatures throughout the measurement. This is also similar with the indoor air velocities which were lower than the outdoor wind speeds at all times. Meanwhile, the results also demonstrate that the average indoor air temperatures were also lower than the indoor predicted comfort temperatures during the morning hours until 1 pm. The overall findings indicate that the architectural characteristics of the selected heritage mosque has a good response to the local climate. However, some improvements are necessary in enhancing the indoor thermal comfort. The findings can be used as guides for achieving a more comfortable indoor environmental condition of heritage mosques, as well as the modern mosques also.

Keywords: Heritage mosque; Indoor environmental condition; Thermal comfort; Air temperature; Air velocity

INTRODUCTION

Heritage architecture is a gem of the country as it records the variety of country's history and culture such as the community and economy development. According to the Malaysia National Heritage Act 2005 (Law of Malaysia, 2006), the word heritage is defined as a generic national heritage, in which this includes the place, object, culture and many more. This national heritage could be either registered or not in the national heritage list. In addition, heritage is also defined as anything that is inherited (Thompson, 1996).

The efforts to appreciate the nation's heritage have begun in Malaysia since 30 to 40 years ago (Azhari & Mohamed, 2012). The establishment of the National Heritage Department of Malaysia in 2006 has also proven that the government appreciates all the heritage of the country. The department is committed in ensuring that all the requirements contained in the National Heritage Act 2005 are complied by the parties involved (Harun, 2011).

A heritage building is referred to a nation's historic building that is valuable for preservation (Thompson, 1996). It includes any building that has heritage value to the society, place or country. Traditional buildings are not definitely specified as heritage buildings as they are normally buildings of custom that represent the place, people or culture. For example, the traditional Malay house that represents the Malay people and culture. Heritage buildings are not specified to certain typology or purposes as they can be of many functions such as transportation buildings, factories, religious buildings, offices, residentials and many more (Darmawan & Enis, 2016).

The studies of heritage places and buildings have been carried out primarily in the area of conservation (Harun, 2011; Azhari & Mohamed, 2012; Llorens & Zanelli, 2016; Mohd Isa et al., 2011), building functions (Darmawan & Enis, 2016; MIsIrlIsoy & Günçe, 2016) and indoor environment (Martinez-Molina et al., 2018; Varas-Muriel et al., 2014). The study of the indoor environment of a building is important to ensure the comfort of the users. The indoor environment is usually influenced by the outdoor environment. In addition, there are also many other factors that affect the indoor environment such as the building design, construction and material selection.

It is important to examine the present indoor environmental condition of a heritage building. This is because the indoor environmental condition of a building encompasses the parameters that respond directly to the current condition of the outdoor environment. The changes in the surrounding environment of a heritage building that occur through time might affect its indoor environmental condition. For example, the urbanization that happens in the area where the heritage building is located will definitely influence the microclimate of that area, such as the wind profile and the air temperature. In addition, the indoor environmental condition of a building is also not associated with the time it is constructed, but it is related to the architectural and technological solutions that are applied in it (Fabbri et al. 2012).

Therefore, this study examines and presents the current indoor environmental condition and thermal comfort of a heritage building, which is a heritage mosque located in Malaysia. Mosque is selected due to its significant role in the community. In addition, the Malaysia heritage mosque also consists of unique architectural style which is different from the modern mosque design. The output of this study provides knowledge whether the architectural and technological solutions applied to the heritage mosque are still appropriate and have good respond to the local climate and environment through time.

INDOOR ENVIRONMENT AND THERMAL COMFORT

The elements that influence in the indoor environment of a building are the thermal, lighting, acoustic and interior conditions, as well as the air quality and ventilation. However, for this study, the focused indoor environmental elements are the thermal condition and ventilation aspect as these two elements are highly influenced by the outdoor condition.

The indoor space is stated to be in thermal comfort condition if the occupants feel satisfied with the thermal environment. The satisfaction feeling is very subjective and various among people as there many many factors related to it. There are thermal comfort models developed by researchers to measure and determine the thermal comfort condition of the occupants. Among them are PMV model and adaptive model.

The PMV model was the initial model used in the thermal comfort study. It was developed by Fanger, and the experiment was executed in the controlled indoor environment. In this model, there are six parameters listed to influence the thermal comfort of people, which are the air temperature, air velocity, relative humidity, mean radiant temperature, metabolic rate and and clothing insulation. As this model was initially developed in a controlled environment, hence, it was stated to be suitable for steady-state environment only (Djamila, 2017).

On the other hand, the adaptive model is indicated to be more suitable for an uncontrolled environment, such as in a free-running building. This is due to the principle of this model which states that people have the ability to adapt themselves to the changes in the environment. This adaptive model was initially developed by Nicol and Humphreys. In their thermal comfort study, they realized that under the real environment, people can tolerate higher range of temperature compared to the range predicted by the PMV model. The ability to adapt themselves to the real condition of the environment depends on many factors such as the cultural background, the climatic condition, as well as the physiological and psychological aspects. In addition, it is also emphasized in the adaptive model that the outdoor air temperature has significant influence to the indoor air temperature (Carlucci et al. 2018).

The selection of appropriate thermal comfort model is very important in deriving reliable findings. The PMV model is more suitable for the air conditioned building which the indoor air temperature is able to be controlled (Caetano et al. 2017). Meanwhile, for the naturally ventilated building, the adaptive model is more appropriate as such building has a continuously changing environment (Caetano et al. 2017; He at al. 2017).

The equation of PMV model is more complex compared to the adaptive model. The equation of adaptive model only requires the input value of outdoor air temperature in deriving the neutral temperature or indoor predicted comfort temperature (Djamila, 2017). Among the adaptive model equation that can be used is (Humphreys et al., 2013):

$$Tn = 13.8 + 0.53\ (\pm 0.02)\ To \tag{1}$$

where To is the average outdoor air temperature, and Tn is the neutral temperature or indoor predicted comfort temperature.

Many studies have been executed on the thermal comfort in the hot and humid climate. Among them are López-Pérez et al. (2019), Huang et al. (2019) and Lau et al. (2019). In addition, there are also previous studies that indicated the ability of people to adapt to their surrounding climate, such as the studies by Caetano et al. (2017) and Yusoff (2017). Their studies demonstrated that people in hot and humid climate are able to feel comfort in higher air temperature.

Caetano et al. (2017) examined the indoor thermal comfort of an office building in Brazil. Though the findings summarized that the thermal comfort range of majority occupants was between 22.5 °C to 25.5 °C, there were still occupants who felt slightly cold or neutral at the indoor air temperature of above 26 °C. Meanwhile, the study by Yusoff (2017) on the thermal comfort of people in Malaysia demonstated that people felt neutral or slightly warm at 33 °C. In addition, majority of them were satisfied with such thermal condition.

The ventilation also affects the thermal comfort of indoor spaces. The preferred comfort temperature may rise with the increase of air movement (López-Pérez et al. 2019). In addition, the indoor heat could also be reduced with the presence of natural ventilation, which is driven by pressure and thermal differences (Huang et al. 2019). The study by Lau et al. (2019) also indicated that occupants in a building that applies natural ventilation can tolerate to wider range of comfort temperature compared to the people in air conditioned building. For hot and humid climate, the recommended air velocity to achieve thermal comfort is 0.8 m/s (Yusoff, 2006 & Candido et al. 2011). Hence, the studies above demonstrated that natural ventilation certainly provides effects to the indoor thermal comfort.

MALAYSIA HERITAGE MOSQUE

As mentioned before, the heritage building can be of many functions, including religious building such as mosque. In Malaysia, there are mosques that have been gazetted as national heritage building such as the Sultan Abdul Samad Jamek Mosque and National Mosque in Kuala Lumpur, Lebuh Acheh Mosque and Kapitan Keling Mosque in Pulau Pinang, Abidin Mosque and Hiliran Mosque in Terengganu, Kampong Hulu and Kampung Keling Mosque in Melaka, and Ubudiah Mosque in Perak. Besides the mosques that are listed in the national heritage list, there are also mosques that have been gazetted as heritage by State Museum Corporation such as Masjid Tanah and Al Hamideen Mosque in Melaka.

The origin design of the early mosques in Malaysia is different from the nowadays, where it has the influence of Malay Archipelago architectural style. According to Ahmad (2015), the architectural style of the old mosques in the Malay Archipelago is characterized by tiered and tapered roof, which is between two to five tiers. Besides that, the layout plan is normally simple, with the form of either square or rectangular. In addition, there is also veranda at the front part of the mosque, or all around it. This is also in accordance with Thalib and Sulieman (2011) who provided example of Air Baroque Village Mosque, located in Jasin, Melaka, as an old mosque that possesses Malay Archipelago architectural style. The mosque was built in 1916. It has tiered and tapered roof, while its layout plan is square shape, and surrounded by verandas.

Compared to the other mosques listed in the national heritage list, this architectural style can be found mostly at the old mosques in Melaka such as Kampung Hulu Mosque, Kampung Kling Mosque, Al Hamideen Mosque and Masjid Tanah. However, this study has selected Masjid Tanah for the initial assessment of the indoor environmental condition and thermal comfort due to its assessibility and availability during the conduction of the study, as well as its uniqueness. The findings from this preliminary study can be extended in future to other heritage mosques that have similar characteristics.

Case Study of Masjid Tanah

A case study has been selected for this preliminary study which is Masjid Tanah. The reason for selecting Masjid Tanah is due to its uniqueness in term of its history, location, construction materials and architectural characteristics. Masjid Tanah is located in the town of Masjid Tanah, and within the district of Alor Gajah, Melaka. Being at the primary junction that connects the traditional streets of the old town, the mosque has become a significant landmark to that area (Figure 1). Moreover, the name of the town, which is Masjid Tanah is also originated from the name of the mosque. There are old shophouses that accommodate heritage businesses around Masjid Tanah. Among the businesses are traditional attire shops, jewellery shops, restaurants and many more. Hence, the streets at the area are categorized as traditional streets as they are located in an old town that possesses historical value. In addition, there is also a river near to Masjid Tanah, which is named as Sungai Baharu (Figure 2).

FIGURE 1. The location of Masjid Tanah

FIGURE 2. Masjid Tanah is also located near a river, named Sungai Baharu

Masjid Tanah was built in 1800s by a Muslim scholar from Gujarat, India. In 1951, the mosque had been renovated to fulfill the needs of the users. Among the renovation done is the provision of detached toilet and ablution area. The original construction material of the mosque is unique as its wall was constructed using the mixture of egg white, sand and laterite. The walls, which are the load bearing walls, have the thickness of 250 mm, which is thicker than the normal brick wall construction nowadays. The unique wall materials have caused the mosque to be named as Masjid Tanah. In English, the word '*tanah'* refers to soil.

These characteristics also reflect the architecture style of Masjid Tanah. The layout plan of the mosque is very simple compared to the modern mosque nowadays. It is rectangular shape, with the dimension of 11.25 meter length and 13.15 meter width. It has one main praying hall which is surrounded by verandas. These verandas become the additional praying areas when the main praying hall exceeds its capacity. There is a small additional space at the front part of the praying hall named '*mihrab'*. It is an area for the '*imam'*, who leads the praying (Figure 3).

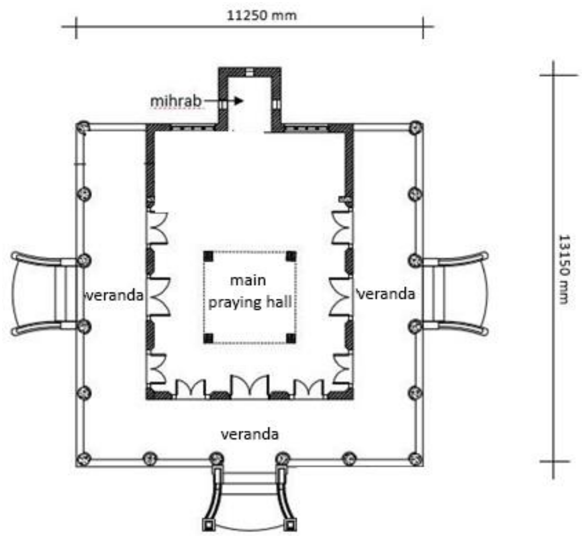

FIGURE 3. The floor plan of Masjid Tanah

The floor of Masjid Tanah is elevated about 0.5 m from the ground, and there are concrete decorative stairs at the front and sides of the mosque. The concrete decorative stair at the entrance is one of the main architectural features for the traditional buildings in Melaka, especially the traditional house.

The main praying area can be assessed via the solid wooden doors that are located at the front and sides of the mosque. Besides doors, there are small openings exist at the '*mihrab'* area. The uniqueness of this mosque is that it has no window. There is only large opening located at the front wall of the main praying hall, in which this opening is decorated with timber grille. Sited on top of this large opening are decorative and coloured glass panels that allow the penetration of daylight into the main praying hall. These glass panels are also available at the tiered roof.

Hence, with all the uniqueness mentioned above, it is undisputable that Masjid Tanah is a valuable heritage to the country. To date, the available documentation of Masjid Tanah is about its history, construction and architectural characteristic. The environmental performance of the mosque is yet to be examined and documented. It is worthy to investigate the indoor air temperature and natural ventilation profile of the mosque, as nowadays moderm mosques in the hot and humid climate have different architectural characteristics.

RESEARCH METHODOLOGY

The research method used in this study is field measurement. The purpose of field measurement is to record the existing outdoor and indoor air temperature and air velocity. For the preliminary study, only these two parameters were focused. This is because the temperature value is essential for the adaptive thermal comfort equation, while the air velocity also has significant effect to the human thermal comfort. The field measurement was executed at Masjid Tanah for two days in the end of March (31th March 2018) and early of April (1st April 2018), from 9 am to 4 pm. As this is a preliminary study, the measurement was executed for short duration only. The equipments used in the measurement were two multiparameter ventilation meters that were TSI Velocicalc 9565 series (Figure 4). Many environmental parameters were able to be measured by the equipment such as the air temperature, air pressure, air velocity and relative humidity.

FIGURE 4. The multiparameter ventilation meter

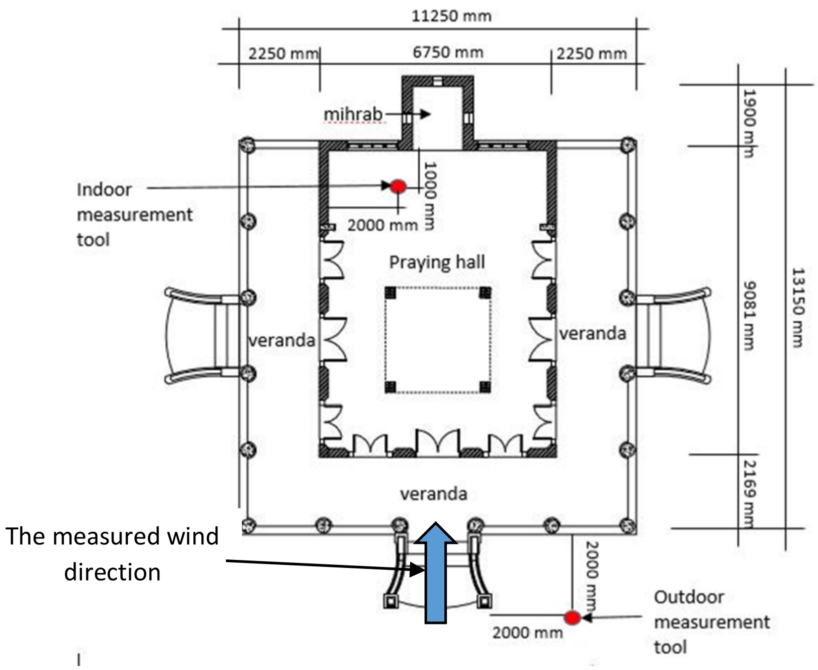

FIGURE 5. The location of the measuring equipments and the measured wind direction

In this study, only two parameters were measured which were the air temperature and air velocity. The accuracy for the air velocity measurement was ±0.015 m/s, while for the air temperature, the accuracy was ±0.3°C. However, there is also restriction to the equipment where it can measure only 180° wind direction. Due to that constraint, the measured air velocity for this study is only in the direction as shown in Figure 5.

The measuring equipments were calibrated prior to the actual measurement. The calibration was conducted by placing all the equipments in parallel, and at similar height, which was about 1 meter from the ground level. The calibration results indicated that the deviation percentages of readings between the two equipmets were 0.3% for the air temperature, and 4% for the air velocity.

Two measuring equipments were necessary as they were placed at two different locations which were the indoor and outdoor of the mosque (Figure 5). The reason was to record the outdoor and indoor air temperature and air velocity. Besides able to record the data, the selected location for the equipmets were also decided with the consideration of their safety as well as not disturbing the users of the mosque.

The sensors of the equipments were adjusted to be at the height of 1.2 meter from the ground level, which was within the height of the human level. Figure

6 depicts the indoor and outdoor placements of the measuring equipments. They were placed on chairs instead of tripod due to the unavailability of tripod during the measurement time. The measured air velocity and air temperature data were recorded every five minutes interval.

(a) (b)

FIGURE 6. The indoor (a) and outdoor (b) placement of the measuring equipment

RESULTS AND DISCUSSION

The measured outdoor and indoor data of air temperature and air velocity were demonstrated in Figures 7 and 8. The measured data shows that the average indoor air temperatures were lower than the average outdoor air temperatures (Figure 7). The lowest average outdoor air temperature was recorded at 4 pm which was 32.9 °C, while the highest was at 11 am, which was 37.8 °C. On contrary, the lowest average indoor air temperature was at 9 am, which was 29.5 °C, while the highest was at 3 pm, which was 32.2 °C. The different times between the lowest and highest average outdoor and indoor air temperatures had indicated that there was a duration for the absorption and storage of heat by the building materials, before it was transferred to the internal environment of the mosque. These heat absorption and storage had caused the increase of indoor air temperature from morning to evening, although the average outdoor air temperature decreased (Figure 7). In addition, the presence of verandas had also prevented direct solar radiation from penetrating into the main prayer hall, thus helping to maintain the lower indoor air temperature compared to the outdoor air temperature.

For the indoor ventilation, the measured data indicated on the lower average indoor air velocity compared to the average outdoor wind speed (Figure 8). The results might be caused by the location of the indoor measuring equipment where there was no direct cross ventilation occurred at that area. As mentioned before, the selection of location for the equipment was based on many factors, which among them was the limitation to areas that did not interfere with the users' activities such as praying.

Throughout the measurement, the lowest wind speed was recorded at 9 am and 4 pm, which was 0.24 m/s, while the highest was at 1 pm to 3 pm, which was 0.35 m/s. This is contrary to the measured indoor air velocities where the lowest velocity was at 2 pm, which was 0.05 m/s while the highest was at 11 am, which was 0.09 m/s.

The results also show that the wind speed has some influence to the indoor air velocity. Throughout the measurement, it was found that the average wind speed values never exceeded 0.5 m/s. This low wind speed values might cause the low indoor air velocity values. Meanwhile, for the average indoor air velocity, the values were below 0.1 m/s. These indoor air velocity values might be higher if the indoor measuring equipment is placed at the area where the direct cross ventilation occurs. The simple layout plan of Masjid Tanah, and the presence of many doors at the sides and front of the main praying hall allow the natural cross ventilation to occur. Nevertheless, to achieve high indoor air velocity values is still a challenge as the outdoor wind speed values are low.

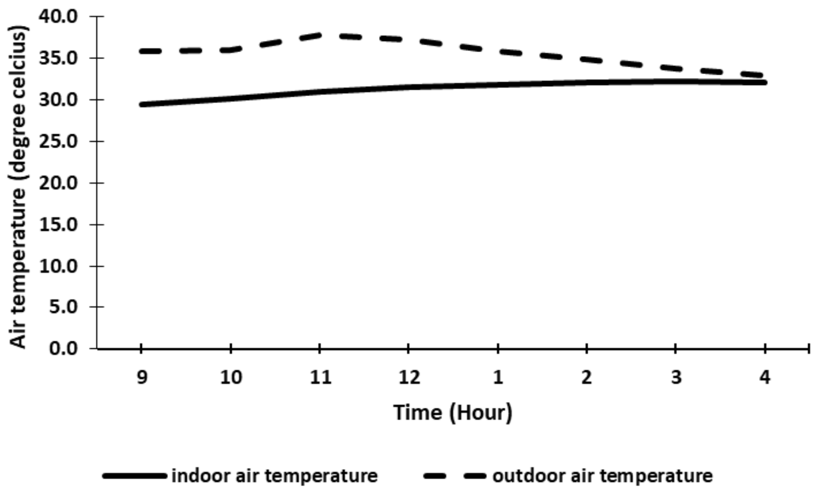

FIGURE 7. The average outdoor and indoor air temperatures

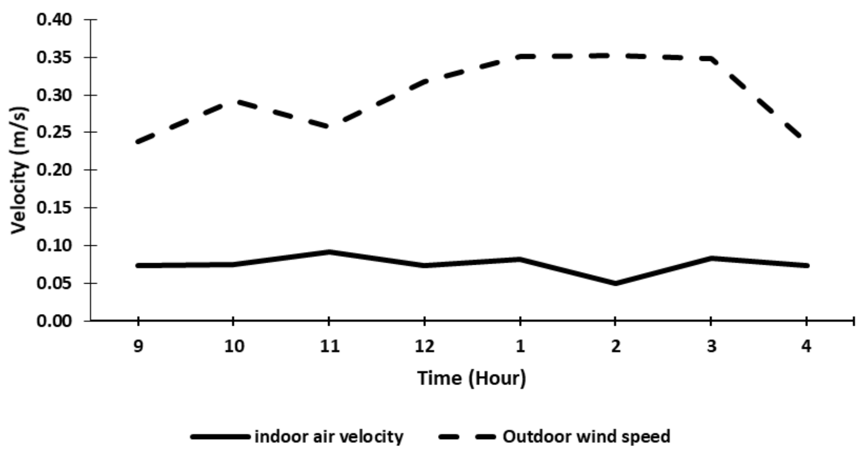

FIGURE 8. The average outdoor wind speeds and indoor air velocities

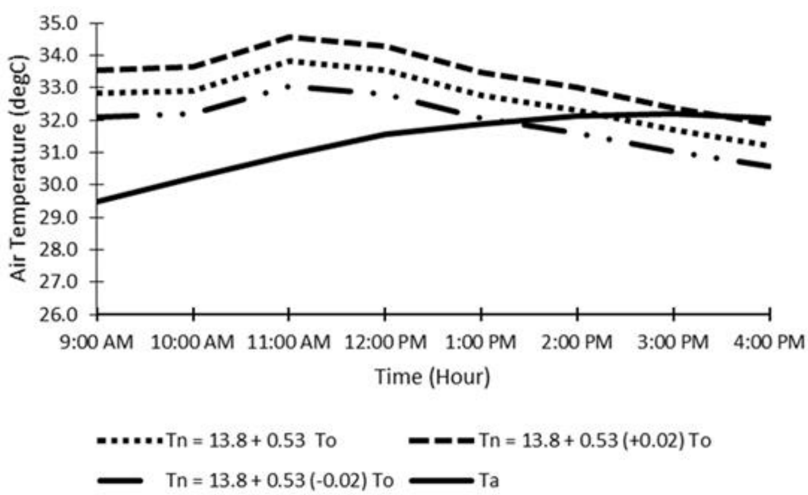

FIGURE 9. The comparison of the measured indoor air temperatures (Ta) and the indoor predicted comfort temperatures (Tn).

In term of thermal comfort, the comparison of the measured indoor air temperatures (Ta) and the indoor predicted comfort temperatures (Tn) is depicted in Figure 9. As mentioned before, the indoor predicted comfort temperature was derived using the adaptive thermal comfort model equation by Humphreys et al. (2013).

The comparison shows that the indoor air temperatures were lower than the indoor predicted comfort temperatures during the morning hours until 1 pm. Though the measured outdoor air temperatures indicated high values during the morning hours which were higher than 35 °C, the thermal comfort at the main praying hall of Masjid Tanah was still able to be achieved.

The study of thermal comfort by Yusoff (2017) for naturally ventilated building stated that in hot and humid climate, people can tolerate to high air temperature, where they still feel neutral at 33 °C. This value is more than the highest indoor air temperature recorded at Masjid Tanah, which was 32.2 °C. Hence, it shows that the indoor environment of Masjid Tanah is able to provide thermal comfort condition to the users.

The thermal comfort condition at the main praying hall of Masjid Tanah is due to the architectural characteristics of the mosque. As mentioned before, the verandas at the sides and front of the mosque are able to prevent the penetration of direct solar radiation into the main praying hall area. In addition, the roof overhang at the veranda also contributes to the comfort indoor environment as it avoids the wall of the main praying hall from receiving direct solar radiation (Figure 10).

FIGURE 10. The veranda of Masjid Tanah

In addition, the wall materials as well as the wall thickness of the mosque which are different from the normal brick wall construction may also contribute to the comfort indoor environment. This heat transfer aspect by the wall of Masjid Tanah is interesting to be studied further in future research.

The thermal comfort of Masjid Tanah may be enhanced further with the increase of indoor air velocity. Nevertheless, it is a challenge to increase the indoor air velocity as the oudoor wind speed is low. Hence, it is suggested in future research to examine the potential of increasing the indoor air velocity at Masjid Tanah.

CONCLUSION

The study shows that the architectural characteristics of Masjid Tanah is able to provide thermal comfort indoor environment to the users. The mosque has architectural characteristics that have good response to the hot and humid climate of Malaysia, such as having veranda, large roof overhang, and simple layout plan with many openings that allow natural cross ventilation. The wall materials and thickness may also contribute to the comfort indoor environment of the mosque. However, this aspect needs to be investigated further in future. The major challenge is in term of the indoor air velocity where at most of the time, the values are lower than the air velocity for comfort in hot and humid climate. In addition, the aim of achieving high indoor air velocity also becomes more challenging with the low outdoor wind speed around the site.

Nevertheless, there are still many valuable architectural characteristics to be learnt from this heritage mosque. The evolution in the modern mosque design nowadays has led to the integration of many active strategies in achieving indoor thermal comfort such as the usage of air conditioning. There are two main passive design strategies need to be incorporated for buildings in hot and humid climate. They are the shading of internal spaces and building facades from the direct solar radiation, and the effective natural ventilation. These two important strategies are sometimes neglected in the design of buildings in hot and humid climate due to the modernization and globalization nowadays.

This study is a preliminary investigation of the indoor environmental condition and thermal comfort of a heritage mosque. With the positive findings derived from this study, it is hoped to initiate more research on heritage buildings especially related to the environmental aspects. Although it is already known that heritage buildings normally have good response to the local climate, the detail investigations using specific measuring equipment will able to enhance the understanding of the actual condition. This understanding will also aid in the effective application of heritage building characteristics at the modern buildings.

ACKNOWLEDGEMENT

The author would like to express gratitude to Universiti Kebangsaan Malaysia and Ministry of Education Malaysia for funding this study under the research grant GUP-2019-017 and FRGS /1/2019/ TK10/UKM /02/4, respectively. The author would also like to thank the UKM architecture students who are Syazani, Sya'ida Nurin, Muhamad Naimmi, Nurul Huda Al-Ameen, Khairul Anwar, Nur Anis Syuhadah, Mohd Hanif and Siti Nurfaridatul Atira for the drawings of Masjid Tanah.

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